

Promoting the Arabica Coffee Production in Dien Bien, Vietnam: Example of plant transition in the mountainous region

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ABSTRACT

Arabica coffee cultivation has become an important driver of sustainable livelihood development and ecological improvement in Vietnam's upland regions. However, the rate of adoption among smallholder farmers remains limited due to diverse socioeconomic and environmental constraints. Using data from the Vietnam Household Agriculture Research Survey, this study investigates the determinants of Arabica coffee adoption among smallholder farmers in Dien Bien Province. Employing probit and OLS regression models, the analysis examines how agricultural inputs, socioeconomic characteristics, infrastructure availability, and environmental stressors affect both adoption decisions and the extent of land allocated to coffee production. The findings indicate that higher investments in labor and fertilizer, frequent extension service contacts, and proximity to paved roads significantly promote the transition to Arabica cultivation. Conversely, competing livelihood strategies such as livestock rearing and non-farm employment detract from Arabica adoption. The study further highlights the role of ethnic minority status in facilitating sustainable farming practices, suggesting that culturally tailored interventions may bolster resilience and market integration. These results underscore the need for integrated policy measures, including improved rural infrastructure and targeted financial support, to foster sustainable agricultural transitions in Vietnam's upland regions.

Key words: *Coffea Arabica*; socioeconomic factors; agricultural inputs; climate resilience; infrastructure.

1 INTRODUCTION

Vietnam stands as the world's second-largest coffee producer, with more than 90% of its total coffee production dominated by Robusta (*Coffea canephora*), a variety that thrives in the country's tropical climate and diverse soil conditions (Vivekananda et al., 2019; Trinh et al., 2020). The prevalence of Robusta has positioned Vietnam as a key player in the global coffee market, primarily supplying coffee for instant blends and lower-cost commercial products. However, in recent years, shifting consumer preferences and the increasing demand for specialty and high-quality coffee have prompted growing interest in expanding the cultivation of Arabica (*Coffea arabica*), a variety known for its superior flavor profile, complex acidity, and higher market value (DaMatta et al., 2007). In response to these market trends, the Vietnamese government has launched targeted initiatives to promote Arabica cultivation in select regions where environmental conditions are favorable, including Dien Bien Province, a mountainous area in the north of the country.

Dien Bien presents an optimal environment for Arabica coffee production due to its cool climate and high-altitude conditions, both of which are essential for producing high-quality coffee beans with desirable sensory characteristics (Bunn et al., 2015; Vaast et al., 2006; Lemma; Megersa, 2021). Given these agroecological advantages, the expansion of Arabica coffee in Dien Bien could contribute to diversifying Vietnam's coffee industry, enhancing farmers' incomes, and

reducing economic risks associated with overreliance on Robusta. Despite these potential benefits, however, Arabica coffee cultivation remains limited in Vietnam, accounting for only a small fraction of total coffee production (Upali et al., 2015; Nab; Maslin, 2020). Scaling up Arabica cultivation requires overcoming significant agronomic, economic, and institutional barriers that have hindered its widespread adoption in Vietnam's coffee-growing regions (Hagggar et al., 2017).

One of the primary challenges associated with transitioning to Arabica coffee is its greater susceptibility to pests, diseases, and adverse climatic conditions compared to Robusta (Ahmed, et al., 2021). Arabica plants require more precise agronomic management and are particularly vulnerable to leaf rust (*Hemileia vastatrix*), coffee berry disease, and other pathogens that can significantly reduce yields (Avelino et al., 2012). Additionally, Arabica cultivation demands higher initial investments in inputs such as shade management, pest control, and soil fertility maintenance, making it a less accessible option for resource-constrained smallholder farmers. Limited access to technical knowledge, financial resources, and extension services further complicates the transition, as farmers often lack the necessary training to implement best practices in Arabica production (Do; Mulia, 2018). In Dien Bien, these challenges are exacerbated by underdeveloped infrastructure, restricted access to markets, and logistical constraints associated with the province's mountainous terrain. Poor road networks and limited transportation options increase

transaction costs and hinder farmers' ability to sell their coffee at competitive prices, further discouraging the shift to Arabica cultivation (Do; Mulia, 2018).

Given these complexities, this study seeks to investigate the socioeconomic, agricultural, and environmental factors that influence the transition to Arabica coffee cultivation in Dien Bien. By identifying the key drivers and barriers to Arabica adoption, this research aims to provide evidence-based insights into the policies and interventions necessary to support farmers in this transition. Furthermore, this study highlights the broader economic and environmental implications of promoting Arabica coffee in Vietnam, particularly in highland regions where diversification efforts could enhance both rural livelihoods and climate resilience. Understanding these dynamics is crucial for designing sustainable agricultural development strategies that align with global market trends while ensuring the long-term viability of coffee farming in Vietnam's evolving agricultural landscape.

2 MATERIAL AND METHODS

This study employs data from the Vietnam Household Agriculture Research Survey (VHAR), a comprehensive dataset that provides detailed insights into the demographic, economic, institutional, and agricultural characteristics of coffee-farming households in Dien Bien Province. The VHAR dataset serves as a valuable resource for understanding the various factors influencing coffee cultivation in this region, offering a rich array of variables that capture the interplay between agricultural inputs, socioeconomic conditions, infrastructure availability, and environmental stressors. By incorporating these diverse dimensions, the study aims to identify the determinants of coffee cultivation practices and the extent of land allocated to coffee production, with a particular focus on the transition to Arabica coffee farming.

The dataset includes a wide range of agricultural input variables, such as expenditures on labor, irrigation fees, pesticide applications, and the use of organic and chemical fertilizers. These variables provide insights into the intensity of farm management and the financial costs associated with coffee cultivation. In addition to agricultural inputs, the dataset also captures key socioeconomic characteristics of farming households, including household head age, education level, gender, and participation in farmer groups or cooperatives. These factors play a crucial role in shaping farmers' decision-making processes, particularly in adopting new cultivation techniques and accessing extension services. Furthermore, environmental variables are incorporated to assess the exposure of coffee farms to climatic hazards, including floods, droughts, and typhoons. Given the sensitivity of Arabica coffee to extreme weather conditions, these environmental factors are critical for evaluating the

long-term viability of coffee production in Dien Bien's mountainous landscape.

Beyond farm-level characteristics, the study also considers infrastructure-related variables, such as proximity to major roads and access to electricity, which can significantly influence production efficiency and market integration. Reliable road networks enhance farmers' ability to procure inputs, access extension services, and transport harvested coffee to markets, while electricity availability facilitates post-harvest processing and mechanization, both of which are crucial for improving productivity and product quality. Recognizing the importance of data completeness for robust econometric analysis, observations containing missing values were systematically excluded from the study to prevent biases and ensure the accuracy of the findings.

To provide an overview of the key variables used in the analysis, Table 1 presents the summary statistics, including the total number of observations, mean values, standard deviations, and the range (minimum and maximum) for each variable. These descriptive statistics offer a preliminary understanding of the variability in coffee farming practices and household characteristics across the surveyed population. By leveraging the VHAR dataset and employing a structured analytical approach, this study aims to generate empirical evidence that informs policies and interventions aimed at supporting the sustainable development of Arabica coffee production in Dien Bien Province.

To systematically examine the factors influencing the adoption of Arabica coffee among farming households, this study employs probit regression models. The probability of a household adopting Arabica coffee is modeled as a function of key determinants, including agricultural inputs, socioeconomic characteristics, infrastructure availability, and environmental conditions. By utilizing this econometric approach, the study aims to identify the extent to which these factors contribute to the decision-making process regarding Arabica coffee cultivation. Specifically, the probit models account for the non-linear nature of adoption behavior, where a household's decision to cultivate Arabica is influenced by both economic incentives and external constraints. The estimated models provide insights into the marginal effects of various independent variables, shedding light on how different factors increase or decrease the likelihood of Arabica adoption.

In addition to analyzing adoption decisions, this study also investigates the determinants of total coffee area cultivated by households through the Ordinary Least Squares (OLS) regression models. These models incorporate the same set of explanatory variables as the probit models, ensuring consistency in the analytical framework while extending the scope of analysis to understand how different factors influence land allocation for coffee production. To enhance the

3 RESULTS

robustness of the results, the OLS regression models include districts and time fixed effects, which control for unobserved regional heterogeneity and temporal variations in agricultural conditions. This methodological refinement ensures that the estimated relationships between independent variables and total coffee area are not biased by location-specific or time-dependent factors.

All statistical analyses are conducted using Stata 17, a widely used econometric software for applied research. The probit regression outputs include estimated coefficients, standard errors, and significance levels, providing a detailed assessment of the relative importance of each predictor in shaping Arabica adoption decisions. Meanwhile, the linear OLS regression results present R-squared and adjusted R-squared values, offering measures of model fit and explanatory power. Together, these econometric models provide a rigorous empirical foundation for understanding the dynamics of Arabica coffee adoption and expansion.

The probit regression analysis presented in Table 2 provides a comprehensive examination of the various factors influencing the likelihood of Arabica coffee adoption among farming households in Dien Bien Province. The model includes two columns: the first reports the estimated coefficients, and the second presents the marginal effects derived from the probit model. Notably, the variables *Eleca* and *Droug* are excluded from the model due to perfect prediction issues. Specifically, all households that adopted Arabica coffee had access to electricity, and none reported drought occurrences in the past three years. As a result, households without access to electricity or those that experienced drought were perfectly predicted not to adopt Arabica, making it impossible to estimate meaningful marginal effects for these variables within the probit framework.

Among the group of agricultural input variables, labor cost, pesticide expenditure, and chemical fertilizer cost are

Table 1: Description and statistics of independent variables. *Currency unit: Vietnamese Dong (VND).*

Description of Variables	Abb	Count	Mean	Sd	Min	Max
Household grows coffee (1 = Yes, 0 = No)	<i>Coffe</i>	1274	0.03	0.18	0	1
Total coffee area (ha)	<i>Areal</i>	1274	0.02	0.15	0	2
State irrigation fee per hectare (thousand VND)	<i>Irrif</i>	1274	14.49	80.29	0	1.4
Labor cost per hectare (million VND)	<i>Labor</i>	1274	0.47	1.50	0	22
Interest on borrowed capital per hectare (million VND)	<i>Intcb</i>	1274	0.02	0.14	0	3
Pesticide cost per hectare (million VND)	<i>Pesti</i>	1274	0.51	0.73	0	13
Organic fertilizer cost per hectare (million VND)	<i>Orgfz</i>	1274	0.41	0.65	0	2
Chemical fertilizer cost per hectare (million VND)	<i>Chemf</i>	1274	1.34	1.88	0	7
Distance to paved roads (km)	<i>Distp</i>	1274	5.78	10.68	0	48
Access to national electricity grid (1 = Yes, 0 = No)	<i>Eleca</i>	1274	0.91	0.29	0	1
Total agricultural land area (ha)	<i>Farma</i>	1274	1.41	1.45	0	15
Membership in socio-political organizations (1 = Yes, 0 = No)	<i>Mborg</i>	1274	0.85	0.35	0	1
Value of livestock activities (million VND)	<i>Livev</i>	1274	39.68	44.36	0	0.4
Household members in farm employment	<i>Farmh</i>	1274	3.67	1.60	0	11
Household members in non-farm employment	<i>Nonfh</i>	1274	0.75	0.97	0	5
Self-employed household members	<i>Selfh</i>	1274	0.33	0.79	0	6
Migrated household members	<i>Migrh</i>	1274	0.20	0.53	0	4
Number of contacts with agricultural extension services	<i>Exten</i>	1274	0.25	0.74	0	10
Age of household head (years)	<i>Agehd</i>	1274	48.74	11.47	28	82
Gender of household head (1 = Male, 0 = Female)	<i>Genhd</i>	1274	0.89	0.31	0	1
Total household members	<i>Hhmem</i>	1274	5.48	1.99	1	15
Education level of household head (years)	<i>Eduhd</i>	1274	4.40	3.85	0	12
Household head's Ethnicity (1 = Hmong, 0 = Otherwise)	<i>Ethhd</i>	1274	0.47	0.50	0	1
Flood occurrence in past 3 years (1 = Yes, 0 = No)	<i>Flood</i>	1274	0.03	0.16	0	1
Drought occurrence in past 3 years (1 = Yes, 0 = No)	<i>Droug</i>	1274	0.02	0.15	0	1
Other disasters in past 3 years (1 = Yes, 0 = No)	<i>Othds</i>	1274	0.09	0.28	0	1

found to have statistically significant effects on the adoption decision. Specifically, a one-million VND increase per hectare in labor and chemical fertilizer costs is associated with an increase in the probability of adoption by 0.09% and 0.19%, respectively. Conversely, a one-million VND increase in pesticide expenditure per hectare reduces the probability of adopting Arabica coffee by approximately 0.25%.

Table 2: Estimation results for transition to coffee production.

	Coef.	dy/dx^i
Irrif	-0.2418 (0.9435)	-0.0022 (0.0086)
Labor	0.1012** (0.0433)	0.0009** (0.0004)
Intcb	-0.1760 (0.7166)	-0.0016 (0.0066)
Pesti	-0.2709* (0.1558)	-0.0025* (0.0014)
Orgfz	0.2102 (0.1321)	0.0019 (0.0012)
Chemf	0.2027*** (0.0473)	0.0019*** (0.0004)
Distp	-0.6976*** (0.2342)	-0.0064*** (0.0018)
Farma	0.2452*** (0.0521)	0.0022*** (0.0005)
Mborg	-0.4043 (0.3281)	-0.0037 (0.0030)
Livev	-4.9357* (2.6402)	-0.0452* (0.0241)
Farmh	-0.0391 (0.0868)	-0.0004 (0.0008)
Nonfh	-0.0057 (0.0886)	-0.0001 (0.0008)
Selfh	-0.1294 (0.1430)	-0.0012 (0.0013)
Migrh	0.0753 (0.1419)	0.0007 (0.0013)
Exten	0.0865 (0.1047)	0.0008 (0.0010)
Agehd	0.0092 (0.0079)	0.0001 (0.0001)
Genhd	0.0542 (0.3516)	0.0005 (0.0032)
Hhmem	0.0338 (0.0742)	0.0003 (0.0007)

Continue.

Table 2: Continuation.

	Coef.	dy/dx^i
Eduhd	0.0022 (0.0282)	0.0000 (0.0003)
Ethhd	0.8937*** (0.2451)	0.0082*** (0.0022)
Flood	-0.2413 (0.5184)	-0.0022 (0.0048)
Othds	0.1261 (0.3046)	0.0012 (0.0028)
_cons	-2.9305*** (0.6134)	
Obs.		1274
Pseudo R2		0.33
District FE		No
Year FE		No

Note: (i) dy/dx is the marginal effect of the probit model

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Regarding infrastructure-related factors, both the distance to paved roads and the total agricultural land area exhibit strong statistical significance. An increase of 1 kilometer in distance to the nearest paved road reduces the probability of adoption by 0.64%, while an additional hectare of agricultural land increases this probability by 0.22%.

The value of livestock activities shows a statistically significant and negative relationship with Arabica adoption. Specifically, a one-billion VND increase in livestock value decreases the probability of transition by 4.52%. In contrast, belonging to the Hmong ethnic minority is positively and significantly associated with adoption: households headed by Hmong individuals are 0.82% more likely to transition to Arabica cultivation.

These findings highlight the critical role of production inputs, infrastructure accessibility, household economic orientation, and ethnic identity in shaping agricultural transitions in the mountainous context of northern Vietnam.

3.2 Determinants of Total Coffee Cultivated Area

The estimation results, as presented in Table 3, offers a detailed examination of the factors that influence the total coffee area cultivated by farming households in Dien Bien Province. Three model specifications are reported, with Model 3 controlling for both district and year fixed effects. Across all specifications, the coefficients remain relatively stable, suggesting robustness in the estimated relationships.

Among the agricultural input variables, labor cost and chemical fertilizer expenditure consistently exhibit positive and statistically significant impacts. Specifically, a one-million VND increase in labor cost per hectare is associated with an increase

of approximately 0.023-0.025 hectares in total coffee area, while a similar increase in chemical fertilizer cost is linked to an expansion of about 0.016 -0.017 hectares. In contrast, pesticide expenditure has a negative and significant impact, implying that higher reliance on chemical pest control may discourage coffee area expansion, possibly due to concerns over input intensity or ecological risk.

Table 3: Estimation results for promoting the coffee area.

	Model 1	Model 2	Model 3
Irrif	-0.0365 (0.0488)	-0.0145 (0.0472)	0.0054 (0.0477)
Labor	0.0227*** (0.0028)	0.0236*** (0.0027)	0.0247*** (0.0027)
Intcb	-0.0187 (0.0276)	0.0019 (0.0266)	0.0032 (0.0266)
Pesti	-0.0184*** (0.0065)	-0.0147** (0.0062)	-0.0153** (0.0062)
Orgfz	-0.0037 (0.0067)	-0.0051 (0.0064)	-0.0033 (0.0070)
Chemf	0.0158*** (0.0026)	0.0177*** (0.0026)	0.0168*** (0.0027)
Distp	-0.0006 (0.0004)	-0.0008* (0.0005)	-0.0009* (0.0005)
Eleca	-0.0068 (0.0146)	-0.0140 (0.0141)	-0.0179 (0.0142)
Farma	0.0197*** (0.0029)	0.0201*** (0.0028)	0.0200*** (0.0029)
Mborg	-0.0043 (0.0118)	0.0037 (0.0116)	0.0026 (0.0116)
Livev	-0.2233** (0.0955)	-0.1254 (0.0971)	-0.1373 (0.0984)
Farmh	0.0015 (0.0036)	0.0027 (0.0034)	0.0031 (0.0035)
Nonfh	-0.0046 (0.0043)	-0.0079* (0.0042)	-0.0074* (0.0042)
Selfh	-0.0064 (0.0050)	-0.0047 (0.0048)	-0.0019 (0.0049)
Migrh	0.0146* (0.0075)	0.0105 (0.0072)	0.0090 (0.0073)
Exten	0.0135** (0.0053)	0.0124** (0.0051)	0.0114** (0.0053)
Agehd	-0.0004 (0.0004)	-0.0002 (0.0003)	-0.0002 (0.0003)
Genhd	0.0111 (0.0134)	0.0083 (0.0129)	0.0085 (0.0130)

Continue.

Table 3: Continuation.

	Model 1	Model 2	Model 3
Hhmem	-0.0005 (0.0029)	-0.0029 (0.0028)	-0.0028 (0.0028)
Eduhd	0.0005 (0.0012)	0.0011 (0.0011)	0.0011 (0.0011)
Ethhd	0.0196** (0.0087)	0.0049 (0.0086)	0.0071 (0.0087)
Flood	-0.0182 (0.0238)	-0.0234 (0.0228)	-0.0229 (0.0228)
Droug	-0.0198 (0.0257)	-0.0191 (0.0246)	-0.0228 (0.0253)
Othds	0.0139 (0.0142)	0.0180 (0.0137)	0.0190 (0.0143)
_cons	-0.0126 (0.0265)	-0.0315 (0.0402)	-0.0941 (0.0979)
Obs.	1274	1274	1274
R-squared	0.14	0.22	0.23
adj R-squared	0.13	0.20	0.20
District FE	No	Yes	Yes
Year FE	No	No	Yes

Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Regarding infrastructure, distance to the nearest paved road shows a small but significant negative effect across all models. Each additional kilometer of distance reduces the coffee area by approximately 0.001 hectares, underscoring the importance of physical accessibility in influencing land allocation decisions. Meanwhile, the total area of agricultural land owned by the household is strongly and positively associated with coffee cultivation, with a marginal effect of about 0.02 hectares per additional hectare of total landholding.

Among the household livelihood variables, the value of livestock production (*Livev*) shows a negative and statistically significant effect in Model 1, with households earning higher income from livestock activities tending to allocate less land to coffee cultivation. Specifically, a one-billion VND increase in livestock value is associated with a reduction of approximately 0.22 hectares in total coffee area, suggesting a possible trade-off between livestock and coffee as competing land-use strategies. However, this effect diminishes and becomes statistically insignificant when regional fixed effects are included.

Regarding non-farm labor (*Nonfh*), the number of household members engaged in non-agricultural employment is associated with a small but significant negative effect in Models 2 and 3. Each additional non-farm worker corresponds to a reduction of roughly 0.007 hectares in coffee area, indicating that diversification into off-farm income may reduce household labor availability or incentives for expanding coffee production.

In contrast, the number of migrated household members (*Migrh*) is positively associated with coffee area in Model 1, with each additional migrant linked to an increase of approximately 0.015 hectares. Although this effect is not statistically significant in later models, it may suggest that migration-related remittances contribute to land investment in agricultural production.

Agricultural extension contact (*Exten*) consistently demonstrates a positive and statistically significant association with coffee cultivation across all models. Each additional interaction with extension services is linked to an increase of around 0.011–0.013 hectares in total coffee area, underscoring the importance of information access and technical guidance in supporting production expansion.

Finally, the ethnicity of the household head (*Ethhd*) shows a positive and significant relationship with coffee area in Model 1, where minority-headed households cultivate, on average, about 0.02 hectares more coffee land than majority-headed ones. Although this relationship becomes statistically insignificant once fixed effects are introduced, it suggests that ethnic minority groups may be more involved in coffee expansion, potentially due to local development initiatives or agroecological advantages in minority-dominated regions.

4 DISCUSSION

The transition to Arabica coffee cultivation in Dien Bien presents a significant opportunity to enhance farmer livelihoods, diversify Vietnam's coffee industry, and strengthen the region's resilience to climate change. Given the increasing global demand for high-quality Arabica coffee, fostering this transition could provide economic benefits to smallholder farmers while reducing Vietnam's overreliance on Robusta production. This study offers valuable insights into the complex interplay of socioeconomic, agricultural, and environmental factors that shape the transition to Arabica coffee cultivation in Dien Bien Province, Vietnam. As a region with significant potential for coffee diversification, Dien Bien faces numerous systemic challenges that influence the pace and extent of Arabica coffee adoption. These findings align with previous research highlighting that adoption of specialty crops in mountainous regions is often constrained by infrastructure deficits and limited institutional support (Jena et al., 2012; Pham et al., 2020). In particular, the critical roles of infrastructure development, human capital investment, and climatic resilience are emphasized in facilitating the expansion of Arabica coffee production in upland areas (Tucker et al., 2010; Byrareddy et al., 2019). The study highlights how well-developed transportation networks, access to agricultural extension services, and improved market linkages can mitigate logistical constraints that often hinder farmers' ability to shift towards Arabica cultivation. Moreover, the role of human

capital particularly in terms of farmers' education, technical training, and experiential knowledge proves to be a decisive factor in their capacity to adopt new agricultural techniques and improve productivity. Equally significant is the influence of climatic resilience, as Arabica coffee requires specific ecological conditions, and farmers must adopt adaptive strategies to manage risks associated with unpredictable weather patterns and environmental stressors.

By situating these findings within the broader academic discourse, this study contributes to the literature on sustainable agricultural transitions in regions with topographical and infrastructural limitations. The results underscore the need for integrated policy frameworks that address both structural and behavioral challenges to Arabica coffee expansion (Glover et al., 2016). Ensuring that smallholder farmers are equipped with the necessary resources and institutional support such as access to credit, secure land tenure, and inclusive cooperatives is critical for a successful transition (World Bank, 2021). Furthermore, these findings have direct implications for policymakers, agribusiness stakeholders, and development practitioners, suggesting that targeted interventions such as investments in rural road networks, capacity-building initiatives, and climate adaptation strategies can enhance the feasibility and sustainability of Arabica coffee cultivation in Dien Bien and similar regions. In light of these insights, this study also identifies several key avenues for future research, including further exploration of farmer decision-making processes, the long-term economic viability of Arabica cultivation under shifting climatic conditions, and the role of digital technologies in facilitating market access and knowledge exchange. By addressing these research gaps, future studies can provide deeper, more nuanced understandings of how coffee-producing communities in Vietnam and beyond can navigate the transition towards high-value, sustainable agricultural systems.

4.1 Aligning Findings with Theoretical and Regional Contexts

The empirical findings of this study align closely with theoretical frameworks on sustainable agricultural transitions, particularly those emphasizing the interplay between resource constraints, institutional support, and environmental suitability in shaping smallholder decision-making.

Firstly, this study contributes to that understanding by empirically validating the roles of input costs, infrastructure, household characteristics, and institutional engagement. In particular, the results confirm that higher labor and chemical fertilizer investments are significantly associated with both Arabica adoption and expanded coffee area. This underscores the capital- and labor-intensive nature of Arabica cultivation, consistent with previous research on the crop's higher input demands and vulnerability to pests and diseases (Ahmed et

al., 2021; Avelino et al., 2012). Meanwhile, the negative relationship between pesticide expenditure and both adoption and area suggests that overreliance on chemical pest control may be symptomatic of unsustainable practices or a response to poor site conditions, discouraging further investment.

Infrastructure emerges as another critical dimension. As found in this study, greater distance from paved roads significantly reduces the likelihood of adoption and limits land allocation for coffee production. These findings resonate with those of Do and Mulia (2018), who emphasized how inadequate road networks in mountainous regions like Dien Bien increase transaction costs, restrict market access, and create logistical barriers to adopting high-value crops such as Arabica. This infrastructural constraint not only affects adoption decisions but also limits the economic scalability of coffee production, posing a challenge for long-term rural development strategies.

The positive association between extension service contact and coffee area, along with the significant role of landholding size, reaffirms the importance of both institutional support and asset endowment. Farmers with more frequent contact with extension agents are more likely to expand coffee cultivation, suggesting that information access and technical guidance play a meaningful role in facilitating adoption at scale. This aligns with findings from Do and Mulia (2018) and Hagggar et al. (2017), who emphasize the enabling role of knowledge systems in overcoming adoption barriers.

In addition, livelihood diversification appears to significantly influence farmers' decisions to transition away from traditional agricultural practices. Specifically, increases in livestock income or non-farm employment opportunities tend to reduce the incentive for households to adopt or expand Arabica cultivation, as attention shifts toward alternative income streams. In contrast, when family members migrate to other areas, the resulting labor shortage and increased autonomy among remaining household members can create favorable conditions for land-use transition, particularly in traditionally cultivated plots.

Additionally, the study highlights the nuanced role of ethnic identity. The positive and significant association between Hmong ethnicity and Arabica adoption supports arguments that cultural background and community-level dynamics can mediate the uptake of agricultural innovations. Given the predominance of ethnic minorities in northern upland Vietnam, recognizing this diversity is vital for designing inclusive interventions (Nab; Maslin, 2020). Specifically, in this context, Hmong people are an ethnic minority group that prefers to live and farm in highland areas well-suited for Arabica cultivation. Thus, ethnic farming communities often engage in practices that reflect local ecological knowledge, and their responsiveness to Arabica incentives may be shaped by traditional land-use patterns and collective experiences with market integration.

4.2 Policy and Practical Implications

The empirical insights generated by this study carry several important implications for policymakers, development practitioners, and agricultural stakeholders aiming to promote Arabica coffee cultivation in mountainous regions like Dien Bien. First and foremost, the strong and consistent influence of labor and fertilizer inputs on both adoption and expansion decisions underscores the need for targeted support that reduces production costs for smallholder farmers. This aligns with findings by Feder et al. (1985), who emphasized the critical role of input accessibility in technology adoption among smallholders. In the context of Vietnam, Nguyen et al. (2021) highlighted that efficient fertilizer management is pivotal for sustainable coffee production, noting that overuse can lead to environmental degradation and increased costs. Interventions such as subsidized access to certified inputs, credit schemes with favorable terms for Arabica investment, or public-private partnerships ensuring reliable supply chains for quality inputs can lower the financial threshold for initial adoption, enabling wider participation among resource-constrained households.

Second, the findings emphasize the critical role of infrastructure development especially road connectivity in enabling agricultural transitions. Dercon et al. (2009) found that improved road access significantly enhances farmers' ability to acquire inputs and access markets, thereby facilitating technology adoption. Similarly, Shamdasani (2020) demonstrated that road accessibility in rural India increased the adoption of agricultural technologies by reducing transportation costs and improving extension service delivery. In Dien Bien, improving rural transportation networks should be a priority, as road upgrades not only facilitate access to input and output markets but also enhance farmers' ability to engage with extension services, cooperatives, and certification programs. Investments in transport infrastructure, particularly in remote ethnic minority areas, would directly address the geographic barriers identified in this study.

Third, the positive relationship between extension contact and coffee area expansion highlights the importance of sustained, localized technical support. Anderson and Feder (2007) emphasized that while extension services are crucial for disseminating information, their effectiveness is significantly enhanced when combined with complementary financial or institutional support. This suggests that information provision alone may not be sufficient to stimulate transitions. Extension strategies should thus be integrated with broader capacity-building programs that combine technical training, demonstration plots, and market-oriented advisory services, focusing on Arabica-specific cultivation practices such as shade management, pest control, and post-harvest processing.

In addition, the results point to the need for integrated land-use planning that accounts for competing agricultural

activities. Barrett, Reardon and Webb (2001) discussed how households make trade-offs between farming systems based on labor demands, land availability, and market potential. The negative association between livestock value and coffee cultivation suggests such trade-offs are at play. Similarly, the negative effect of non-farm employment indicates that livelihood diversification can shift household priorities away from high-investment agricultural transitions like Arabica. Conversely, migration appears to facilitate land-use transformation, possibly due to labor shortages or greater decision-making autonomy among remaining household members. These findings underscore the complexity of rural livelihood systems and suggest that crop promotion policies should be aligned with broader strategies to support livelihood flexibility and resilience.

The observed positive association between ethnic minority status and Arabica adoption signals an opportunity to build upon culturally embedded practices and community strengths. Altieri et al. (2015) emphasized the importance of culturally adapted agricultural practices in promoting sustainable farming among marginalized communities. Development initiatives should be inclusive and responsive to the specific needs and capacities of ethnic groups, many of whom reside in agroecologically suitable but socioeconomically marginalized areas. Tailored interventions such as culturally adapted training materials, local language extension, or ethnic minority farmer cooperatives can enhance engagement and ensure that Arabica promotion contributes to both economic and social inclusion.

Lastly, it is noteworthy that extreme weather conditions, such as floods or droughts, were not found to have a statistically significant effect on either Arabica adoption or coffee area expansion in Dien Bien. This suggests that the land areas currently used for coffee cultivation in the province may have been carefully selected to minimize vulnerability to climatic shocks particularly drought, which has had severe impacts on coffee productivity in Vietnam's traditional Robusta-growing regions (Nguyen et al., 2021). The absence of significant weather-related constraints in this context highlights the potential of Dien Bien as a resilient zone for Arabica development and suggests that environmental screening and agroecological planning have played a role in shaping sustainable land-use strategies.

In sum, fostering a successful transition to Arabica coffee in Dien Bien and similar regions will require a holistic and place-based policy approach that combines financial support, infrastructure investment, institutional strengthening, and sociocultural sensitivity. These measures, taken together, can help unlock the potential of Arabica cultivation as a sustainable livelihood strategy in Vietnam's upland agricultural landscapes.

5 CONCLUSIONS

The study identifies the key drivers and constraints of Arabica coffee adoption in Dien Bien Province, highlighting the roles of labor and input investments, extension services, and infrastructure access. Competing livelihoods, such as livestock and off-farm work, hinder adoption, while ethnic identity and cultural practices influence decisions. Arabica cultivation is not yet limited by climate conditions, suggesting favorable zones. Integrated policies combining infrastructure, finance, and culturally sensitive support are essential for sustainable expansion in upland Vietnam.

6 AUTHORS CONTRIBUTIONS

Conceptual Idea: Luong, B.V.; Dung, N.D.; Methodology Design: Luong, B.V.; Dung, N.D.; Data Collection: Dung, N.D.; Nhu, D.V.; Data Analysis and Interpretation: Luong, B.V.; Dung, N.D.; Nhu, D.V.; Writing and Editing: Dung, N.D.; Nhu, D.V.

7 DATA AVAILABILITY STATEMENT

Data available upon request to authors.

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